DEPOMOD PREDICTIONS FOR AN AQUACULTURE SITE AT CHENEY HEAD, NEW BRUNSWICK

Context

On 19 April 2012, Fisheries and Oceans Canada's (DFO) Habitat Management Division (HMD), Maritimes Region, requested that DFO Science conduct runs of the organic deposition model DEPOMOD for a finfish aquaculture site at Cheney Head, near Grand Manan Island, New Brunswick. The request for science advice is in support of HMD's review of a request for an increase in production at the existing marine finfish aquaculture. Specifically, HMD asked:

1) When running DEPOMOD with resuspension off, what is the area of sensitivity for organic enrichment predicted for the proposed aquaculture site at Cheney Head based on a stocking level of 500,000 fish at the
    i) maximum daily feed rate?
    ii) average daily feed rate?

2) When running DEPOMOD with resuspension on, what is the area of sensitivity for organic enrichment predicted for the proposed aquaculture site at Cheney Head based on a stocking level of 500,000 fish at the
    i) maximum daily feed rate?
    ii) average daily feed rate?

3) At what daily feed rate would the deposition rate of 5 g C m^{-2} d^{-1} be exceeded at the site and what level of stocking would that support when running DEPOMOD with
    i) resuspension off?
    ii) resuspension on?

4) Using feed rates from the Cheney Head site during the time of Tier I monitoring in 2010 and 2011, how do DEPOMOD predictions compare to actual monitoring results when running the model with
    i) resuspension off?
    ii) resuspension on?

DFO's Science Special Response Process was used to respond to this request due to the short deadline for advice of June 15, 2012. This Science Response report was developed and reviewed through email correspondence. No review meeting was held.

Background

HMD, Maritimes Region, is reviewing a request for an increase in production at an existing marine finfish aquaculture site at Cheney Head, near Grand Manan Island, New Brunswick (Appendix 2: Figure 2.1), to determine if it is likely to result in negative impacts to fish and fish habitat under the Federal *Fisheries Act* and will be providing advice to the New Brunswick Department of Agriculture, Aquaculture and Fisheries (NBDAAF) as part of the provincial application process for production increases. This farm stocked 5 cages in 2010 and is now

requesting an expansion to 18 cages. Information on the size, depth, stocking density, and feed rates of these cages is provided in Tables 2.4 and 2.5 (Appendix 2), and the orientation of cages is shown in Figures 2.4 and 2.5 (Appendix 2). One component identified in the HMD risk assessment of the proposed aquaculture development project is the risk of organic enrichment induced impacts on fish habitat in the vicinity of the proposed development site.

Analysis

DEPOMOD (version 2) software was used to predict the near-field deposition of organic solid wastes released from the proposed farm. DEPOMOD is a commercially available computer model (Cromey et al. 2000, 2002) that was developed in Scotland, and has been used to predict the benthic impacts of salmon farming in British Columbia (Chamberlain and Stucchi 2007; Chamberlain et al. 2005). Studies on the use of DEPOMOD have also been conducted at some existing and proposed salmon farms in southwestern New Brunswick (SWNB) (Page et al. 2009; DFO 2009; DFO 2012; Chang et al. 2012) and Nova Scotia.

Using cage locations and dimensions, feed rates per cage, current velocity data, bathymetry, feed wastage rates, and feed and fecal particle sinking rates, DEPOMOD estimates the spatial distribution of organic carbon deposition on the seafloor in the vicinity of the site (in g C m^{-2} d^{-1}) resulting from estimates of waste feed and feces produced by farmed fish in cages. These deposition rates can be related to benthic classifications for fish farms in southwestern New Brunswick, based on sediment sulfide concentrations (NBDENV 2006), using Table 2.2 (Appendix 2; based on information in Hargrave et al. 2008 and Hargrave 2010). It should be noted that the relationship shown in this table was based upon the results of studies in areas where resuspension was likely not a major contributing factor to the resulting benthic conditions (i.e. sites with low bottom current speeds).

DEPOMOD includes a resuspension module that can be turned off or on. When the resuspension module is turned off, the model output is the initial predicted waste deposition rate due to uneaten feed and feces. When the resuspension module is turned on, some of the deposited waste is transported away from the farm. The resuspension module was validated at some Scottish salmon farms (Cromey et al. 2002) where average near-bottom current speeds were low (3.6-6.2 cm s^{-1}). However, at a British Columbia farm, where the average near-bottom current speed was higher (7.9 cm s^{-1}), running DEPOMOD with the resuspension module turned on was found to overestimate the transport of wastes away from farms (Chamberlain and Stucchi 2007). This also appears to be the case at some farms in SWNB where DEPOMOD has been tested, except where current speeds are very low (Chang et al. 2012). This suggests that DEPOMOD predictions with resuspension turned on should be used with caution, as it is not known if the threshold resuspension current speed of approximately 9.5 cm s^{-1} (near bottom), as well as the default consolidation time of 4 days, are appropriate for the conditions at the farm examined in this study. A DFO Science advisory meeting held in February 2005 recommended that the resuspension module be turned off when using DEPOMOD to assess the impacts associated with aquaculture (DFO 2005).

The following describes the outputs from the DEPOMOD runs that were completed in relation to the proposed aquaculture site. Detailed information pertaining to the methodology and data inputs used in the DEPOMOD runs are located within Appendix 1.

Response

Current Velocity

Information on the collection of the current velocity data can be found in Appendix 1. Current rose diagrams for the proposed site are shown in Figure 2.2 (Appendix 2). Currents were predominantly to the south at all 3 depths, with some flow to the north-northwest.

Histograms and summary data for current speeds are shown in Figure 2.3 and Table 2.8 (Appendix 2). Current speeds were high, and there was little variation in the minimum, mean, and maximum speeds among the three depth layers. The percentage of near bottom (4.5 m above seafloor) records greater than the DEPOMOD resuspension threshold of approximately 9.5 cm s^{-1} was high, 69%.

Carbon Deposition Rates (total stocking level 500,000 fish)

Mass balance calculations for the DEPOMOD predictions for a total stocking level of 500,000 fish are shown in Table 2.9 (Appendix 2). For both maximum (902 kg d^{-1}) and average feed rates (255 kg d^{-1}), all waste particles remained within the model domain with resuspension off, but all waste particles were removed from the model domain with resuspension on.

Resuspension Off

With resuspension off and the proposed **maximum** feed rate (902 kg d^{-1}), DEPOMOD predicted large areas with elevated carbon deposition rates (Appendix 2: Table 2.10 and Figure 2.4,): 48,800 m^2 with carbon deposition rates >5 g C m^{-2} d^{-1} and 33,800 m^2 with anoxic conditions (>10 g C m^{-2} d^{-1}).

With resuspension off and the proposed **average** feed rate (255 kg d^{-1}), the predicted area with deposition rates >5 g C m^{-2} d^{-1} was reduced to 7,400 m^2 and there were no areas with anoxic conditions (Appendix 2: Table 2.11 and Figure 2.4).

The highest predicted deposition rate within the DEPOMOD domain using the proposed maximum feed rate was 22.0 g C m^{-2} d^{-1}, more than three times higher than when using the proposed average feed rate, 6.2 g C m^{-2} d^{-1}.

The estimated feed rate that would maintain the predicted deposition rate ≤5 g C m^{-2} d^{-1} in all grid cells within the DEPOMOD domain (derived from the linear relationship between the feed rate and the highest predicted deposition rate within the DEPOMOD domain; see Appendix 2: Table 2.12) was 205 kg d^{-1} per cage (assuming the same number of cages). During the period of maximum feeding (when fish biomass is highest), this feed rate would support a stocking rate of 6,300 fish per cage (compared to proposed stocking of 27,777 fish per cage; Appendix 2: Table 2.13).

Resuspension On

With resuspension on, there was no waste deposition within the model domain, using both maximum and average feed rates; the highest predicted deposition rates within the DEPOMOD domain were <0.1 g C m^{-2} d^{-1} using both feed rates. Therefore, there were no areas with deposition rates >5 g C m^{-2} d^{-1} when using the proposed maximum and average feed rates (Appendix 2: Tables 2.10 and 2.11).

The average near-bottom current speed at the Cheney Head site (14.9 cm s^{-1}) was much higher than the average near-bottom current speeds in the Cromey et al. (2002) and Chamberlain and Stucchi (2007) studies.

Carbon Deposition Rates (2010 and 2011: total stocking level 100,000 fish)

Tier 1 monitoring was conducted at the Cheney Head site on 2 September 2010 and 9 September 2011. In both years, triplicate sediment samples were taken at two locations (Appendix 2: Figure 2.5). The average sediment sulfide concentrations at the two Tier 1 monitoring locations in September 2010 were 222 and 476 µM (both Oxic A), while the maximum sulfide concentration (of all 6 subsamples) was 713 µM (Oxic A; at T2). The average sediment sulfide concentrations at the two Tier 1 monitoring locations in September 2011 were 219 and 1,191 µM (Oxic A and Oxic B; the overall average was Oxic A), while the maximum sulfide concentration (of all 6 subsamples) was 1,580 µM (Hypoxic A; at T2).

Using the cage configuration, stocking level, and feed rates per cage in September 2010, with resuspension off, the predicted deposition rates at the two Tier 1 monitoring locations in September 2010 were 1.3 and 2.9 g C m^{-2} d^{-1} (Oxic B and Hypoxic A), while the maximum predicted deposition rate was 3.4 g C m^{-2} d^{-1} (Hypoxic A; near T2) (Appendix 2: Table 2.14,). There were no areas with deposition rates >5 g C m^{-2} d^{-1} (Appendix 2: Table 2.15 and Figure 2.3). With resuspension on, there was no waste deposition within the model domain.

Using the cage configuration, stocking level, and feed rates per cage in September 2011, with resuspension off, the predicted deposition rates at the two Tier 1 monitoring locations in September 2011 were 13.1 and 19.1 g C m^{-2} d^{-1} (both Anoxic), while the maximum predicted deposition rate was 22.1 g C m^{-2} d^{-1} (Anoxic; near T2) (Appendix 2: Table 2.14). There was an area of 14,900 m^2 with deposition rates >5 g C m^{-2} d^{-1}, including 8,800 m^2 with anoxic rates (Appendix 2: Table 2.15 and Figure 2.5). With resuspension on, there was no waste deposition within the model domain.

In both years, there were positive relationships between the Tier 1 sediment sulfide concentrations and the DEPOMOD predicted carbon deposition rates (with resuspension off) at the same locations (Appendix 2: Figure 2.6). However, in 2011, the DEPOMOD predicted deposition rates were about ten times higher than in 2010 (for equivalent sulfide concentrations).

The results indicate that DEPOMOD, with resuspension off, overestimated the amount of waste deposition on the seafloor under the farm, especially in 2011. With resuspension on, DEPOMOD underestimated the amount of deposition under the farm in both years.

Summary

The following responses address the specific questions asked by HMD. These responses assume that the area of sensitivity is the area where DEPOMOD predicts that the carbon deposition rate will exceed 5 g C m^{-2} d^{-1}.

1) When running DEPOMOD with resuspension off, what is the area of sensitivity for organic enrichment predicted for the proposed aquaculture site at Cheney Head based on a stocking level of 500,000 fish at the

    i) maximum daily feed rate (over the entire production cycle): 48,800 m^2

ii) average daily feed rate (over the entire production cycle): 7,400 m^2

2) When running DEPOMOD with resuspension on, what is the area of sensitivity for organic enrichment predicted for the proposed aquaculture site at Cheney Head based on a stocking level of 500,000 fish at the

   i) maximum daily feed rate (over the entire production cycle): 0 m^2
   ii) average daily feed rate (over the entire production cycle): 0 m^2

3) At what daily feed rate would the deposition rate of 5 g C m^{-2} d^{-1} be exceeded at the site (in any cell within the DEPOMOD domain) and what level of stocking would that support when running DEPOMOD with

   i) resuspension off: feed rate 205 kg d^{-1} per cage; stocking level 6,300 fish per cage (assuming the same number of cages)
   ii) resuspension on: deposition rates never exceeded 5 g C m^{-2} d^{-1} within the DEPOMOD domain.

4) Using feed rates from the Cheney Head site during the time of Tier I monitoring in 2010 and 2011, how do DEPOMOD predictions compare to actual monitoring results when running the model with

   i) resuspension off: The DEPOMOD predicted deposition rates were considerably higher than the observed impacts. The predicted deposition rates at the two Tier 1 monitoring locations in September 2010 were in the Oxic B and Hypoxic A categories, and the maximum predicted deposition rate was in the Hypoxic A category. The average sediment sulfide concentrations at the two Tier 1 monitoring locations in September 2010 were both in the Oxic A category, and the maximum sulfide concentration (of all subsamples) was also in the Oxic A category. The predicted deposition rates at the two Tier 1 monitoring locations in September 2011 were both in the Anoxic category, as was the maximum predicted deposition rate. The average sediment sulfide concentrations at the two Tier 1 monitoring locations in September 2011 were in the Oxic A and Oxic B categories, while the maximum sulfide concentration (of all subsamples) was in the Hypoxic A category.

   ii) resuspension on: for both years, DEPOMOD predicted no deposition within the model domain, while the Tier 1 monitoring indicated sulfide concentrations slightly above background levels, but with overall averages in the Oxic A category in both years.

Conclusions

With resuspension off and using the proposed maximum feed rate, DEPOMOD predicted a large area (48,800 m^2) with deposition rates >5 g C m^{-2} d^{-1}, including 33,800 m^2 with >10 g C m^{-2} d^{-1} (deposition rates that could potentially lead to sediment anoxia, based on the Hargrave et al. (2008) and Hargrave (2010) relationships). Using the proposed average feed rate (and resuspension off), there were some areas with elevated impacts (7,400 m^2 with deposition rates >5 g C m^{-2} d^{-1}), but none with deposition rates >10 g C m^{-2} d^{-1}.

With resuspension on, DEPOMOD predicted no deposition within the model domain, using maximum and average feed rates.

Considerable reduction in feed and stocking rates would be required to keep DEPOMOD predicted deposition rates ≤5 g C m^{-2} d^{-1} at all grid cells within the model domain at the time of maximum feeding (highest fish biomass) at the site, based on the DEPOMOD prediction with resuspension off.

DEPOMOD predictions with resuspension off appear to have overestimated the actual seafloor impacts as measured in the 2010 and 2011 Tier 1 monitoring of this site (when stocked with 100,000 fish in 5 cages), while DEPOMOD predictions with resuspension on underestimated the impacts. It should be noted that DFO (2005) recommended that the resuspension module be turned off when using DEPOMOD to assess the impacts associated with aquaculture.

The above conclusions are based on the assumption that the current meter record is representative of the area of interest and that the predicted deposition rates are related to sediment sulfide concentrations and sediment oxygen concentrations as indicated by Hargrave (2010).

Contributors

Name	*Affiliation*
J. Chamberlain	DFO Science, Pacific Region
B. Chang	DFO Science, Maritimes Region
R. Losier	DFO Science, Maritimes Region
F. Page	DFO Science, Maritimes Region
T. Sutherland	DFO Science, Pacific Region

Approved by:

Sherry Niven
A/Regional Director, Science
DFO Maritimes Region
Dartmouth, Nova Scotia
Ph. 902-426-3490

Date: August 17, 2012

Sources of Information

Chamberlain, J., and D. Stucchi. 2007. Simulating the effects of parameter uncertainty on waste model predictions of marine finfish aquaculture. Aquaculture 272: 296-311.

Chamberlain, J., D. Stucchi, L. Lu, and C. Levings. 2005. The suitability of DEPOMOD for use in the management of finfish aquaculture sites, with particular reference to Pacific Region. Can. Sci. Advisory Sec. (Fisheries and Oceans Canada) Res. Doc. 2005/035: 53 p. Available at: http://www.dfo-mpo.gc.ca/CSAS/Csas/DocREC/2005/RES2005_035_e.pdf (accessed July 2012)

Chang, B.D., F.H. Page, R.J. Losier, and E.P. McCurdy. 2012. Predicting organic enrichment under marine finfish farms in southwestern New Brunswick, Bay of Fundy: comparisons

of model predictions with results from spatially-intensive sediment sulfide sampling. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/078.

Cromey, C.J., T.D. Nickell, and K.D. Black. 2000. DEPOMOD (v2.2.1) user manual. Scottish Environment Protection Agency, Stirling, UK.

Cromey, C.J., T.D. Nickell, and K.D. Black. 2002. DEPOMOD – modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214: 211-239.

DFO. 2005. Assessment of Finfish Cage Aquaculture in the Marine Environment. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/034.

DFO. 2009. Water currents, drifter trajectories and the potential for organic particles released from Little Musquash Cove to enter the Musquash MPA. Can. Sci. Advis. Sec. Sci. Resp. 2009/001. Available at: http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ScR-RS/2009/2009_001_e.pdf (accessed July 2012).

DFO. 2012. Review of DEPOMOD predictions versus observations of sulfide concentrations around five salmon aquaculture sites in southwest New Brunswick. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/042.

Hargrave, B.T. 2010. Empirical relationships describing benthic impacts of salmon aquaculture. Aquacult. Environ. Interact. 1: 33-46.

Hargrave, B.T., M. Holmer, and C.P. Newcombe. 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Mar. Poll. Bull. 56: 810-824.

NBDENV (New Brunswick Department of Environment). 2006. The Environmental Management Program for the Marine finfish Cage Aquaculture Industry in New Brunswick, version 2.0. NBDENV, Fredericton, NB. 21 p. Available at: http://www.gnb.ca/0009/0369/0017/pdfs/0010-e.pdf (accessed July 2012).

Page, F.H., B. Chang, R. Losier, and P. McCurdy. 2009. Water currents, drifter trajectories, and the estimated potential for organic particles released from a proposed salmon farm operation in Little Musquash Cove, southern New Brunswick to enter the Musquash Marine Protected Area. DFO Can. Sci. Advis. Sec..Res. Doc. 2009/003. Available at: http://www.dfo-mpo.gc.ca/CSAS/Csas/Publications/ResDocs-DocRech/2009/2009_003_e.pdf (accessed July 2012).

Appendices

Appendix 1: Methodology and Input Data

Methodology

Cage locations and sizes, proposed feed rates, and current velocity data were provided by the proponent. Current velocity data were collected by DFO St. Andrews Biological Station using a Teledyne RD Instruments 300 kHz Workhorse Sentinel Acoustic Doppler Current Profiler (ADCP), moored on the seafloor within the lease boundary. The location, time, and duration of the current meter deployment are shown in Table 2.1 (Appendix 2). The meter deployment was prior to the farm beginning operations. The ADCP measured current speed and direction at 1-m depth intervals throughout the water column. The ADCP was calibrated by Teledyne RD, and its compass checked and rotated, prior to deployment.

DEPOMOD (version 2) was used to predict carbon deposition rates, using the scenario of continuous release of feed; this is the scenario typically used for proposed or operational farms (Cromey et al. 2000). The model predicts deposition rates within domain and grid cell sizes defined by the user. The domain size for this study was 1000 × 1000 m and the grid cell size was 10 × 10 m. DEPOMOD allows the user to define separate major and minor grids; however, in this study, only one grid was used for the entire domain.

DEPOMOD includes a sediment resuspension module, which has the option to have resuspension turned on or off. The model was first run with resuspension turned off and then with resuspension on. The threshold (critical shear stress) for resuspension in DEPOMOD is fixed by the software at a near-bottom current speed of approximately 9.5 cm s^{-1}. Resuspension only affects unconsolidated particles; the model was run using the default particle consolidation time of 4 days; this assumes that particles sitting on the bottom for ≥4 days are consolidated into the bottom sediment matrix.

The model was run for 2 loops of the current meter record, as recommended in the DEPOMOD manual in order to achieve a steady state solution (Cromey et al. 2000). The output selected was carbon flux, in g C m^{-2} yr^{-1} (at the centre of each grid cell). These carbon flux values were converted to g C m^{-2} d^{-1}.

Contour plots of the predicted carbon deposition rates at the centre of each grid cell were produced using MapInfo Vertical Mapper (version 3.1.1) software. The interpolation technique was Rectangular; the contouring software recommends this technique when data points are evenly distributed, as in DEPOMOD outputs. Default values for cell size and search radius were used. The contour intervals were defined by the carbon deposition rates corresponding to the sediment classifications in Table 2.2 (Appendix 2). Deposition rates <0.3 g C m^{-2} d^{-1} were considered to be background levels; this was the carbon deposition rate at control sites in SWNB reported by Hargrave (1994).

Mass balance calculations compared the DEPOMOD predicted total rate of waste production by the farm (waste feed and feces) with the predicted rate of waste deposition on the seafloor within the model domain. The total rate of waste production was calculated as the total feed rate (all cages combined) multiplied by the rate of waste production per unit of feed. The waste production rate per unit of feed was calculated by DEPOMOD based on the input feed characteristics. Using the feed characteristics in Table 2.3 (Appendix 2), the model estimated the waste production rate per unit of feed (waste feed plus feces) to be 0.044 kg C per kg feed. The total rate of waste deposition within the model domain was calculated as the sum of the

predicted waste deposition rates in all grid cells. The waste deposition rate in each grid cell was calculated as the estimated deposition rate at each grid point (in g C m^{-2} d^{-1}) multiplied by the size of each grid cell (100 m^2).

In cases where the predicted carbon deposition rate exceeded 5 g C m^{-2} d^{-1} in any of the grid cells within the DEPOMOD domain, there was interest in determining the highest feed rate that would result in the carbon deposition rates in all grid cells being maintained below this value. In DEPOMOD, the relationship between the feed rate and the highest predicted carbon deposition rate (in any grid cell) is linear when resuspension is turned off:

$$D_{Max} = a + bF$$

where D_{Max} is the highest predicted carbon deposition rate (g C m^{-2} d^{-1}) of all grid cells in the DEPOMOD domain, F is the feed rate (kg d^{-1} per cage), a is the deposition rate when there is no feed, and b is the rate of deposition per unit of feed. The values for a and b for any site can be determined by plotting the feed rate versus the maximum predicted carbon deposition rate for two or more feed rates at each site. F_{D5}, the feed rate that would result in D_{Max} = 5 g C m^{-2} d^{-1} can then be estimated from the relationship. S_{D5}, the highest number of fish per cage which will maintain $D_{Max} \leq 5$ g C m^{-2} d^{-1}, can then be calculated as

$$S_{D5} = \frac{F_{D5}}{F_{Max}} S_{\mathrm{Proposed}}$$

where F_{Max} is the proposed maximum feed rate (in kg d^{-1} per cage), and $S_{Proposed}$ is the proposed number of fish per cage.

Input Data

Production information for the farm at the proposed new stocking rate is given in Table 2.4 (Appendix 2). It is proposed to stock a total of 500,000 smolts in 18 cages. DEPOMOD was run using the proposed maximum and average feed rates per cage.

This site has been in operation since 2010, when it stocked 5 cages with a total of approximately 100,000 salmon (Appendix 2: Table 2.5). Environmental Monitoring Plan Tier 1 monitoring was conducted in the fall of 2010 and 2011. Feed rates per cage were obtained from the operator for time periods corresponding to the dates of the Tier 1 monitoring in 2010 and 2011 (Appendix 2: Table 2.3). DEPOMOD was then run using these feed rates with a total of 100,000 fish stocked in 5 cages (20,000 fish per cage).

For current velocity input, hourly records (the default time step) were extracted for three depth layers (the number of layers recommended by Cromey et al. 2002) from the raw current meter datafiles, after the datafiles were checked for errors. The three depth layers were: near surface, mid-depth, and near bottom (Appendix 2: Table 2.6).

Bathymetry data were obtained from the Canadian Hydrographic Service (CHS). The data indicate that the seafloor in the vicinity of the site slopes downward from west to east, with the average depth (relative to chart datum, lowest normal tide) within the lease area being 15.2 m (range: 8.7-18.0 m). A grid of depth values corresponding to the centre of each DEPOMOD grid cell was created by interpolation from the CHS data.

The mean tidal height (mean water level above chart datum) was set at 3.1 m above chart datum in the DEPOMOD main input dialog screen, using CHS data from the nearest reference or secondary port (Outer Wood Island, NB). Mean water level data can be found in the latest edition of the Canadian Tide and Current Tables, Volume 1 (Atlantic Coast and Bay of Fundy).

Other DEPOMOD input values used are shown in Table 2.7 (Appendix 2). In most cases, these were values recommended for British Columbia (Stucchi and Chamberlain 2005) or default values.

Appendix 2: Tables and Figures

Table 2.1. Location, dates, and duration of the current meter deployment at the Cheney Head salmon farm (see Figure 2.1).

Location	Deploy-ment	Latitude	Longitude	Start date	End date	Duration (days)
Cheney Head (MF-503)	CM308	44.65452°N	66.70890°W	28 Aug 2002	08 Oct 2002	41

Table 2.2. Site classifications for fish farms in New Brunswick (NBDENV 2006) based on sediment sulfide concentrations, with equivalent carbon deposition rates (based on Hargrave et al. 2008 and Hargrave 2010).

Site classification: New Brunswick	Sediment sulfide concentration (µM)	Carbon deposition rate (DEPOMOD) (g C m^{-2} d^{-1})
Oxic A	<750	<1.0
Oxic B	750–1,500	1.0–2.0
Hypoxic A	1,500–3,000	2.0–5.0
Hypoxic B	3,000–4,500	5.0–7.5
Hypoxic C	4,500–6,000	7.5–10.0
Anoxic	>6,000	>10.0

Table 2.3. Feed rates per cage at the Cheney Head site corresponding to the dates of Tier 1 monitoring: 2 September 2010 and 9 September 2011, with a stocking level of 100,000 fish in 5 cages.

	Average feed rate per cage (kg d^{-1})	
Cage	29 Aug-25 Sep 2010	28 Aug-24 Sep 2011
1	179	1,107
2	152	1,108
3	162	1,009
4	153	1,031
5	153	1,090
Average	160	1,069

Table 2.4. Production information for a proposed production increase at the Cheney Head salmon farm.

Parameter	Value
Total number of fish	500,000
Lease area	26.5 ha
Number of cages	18
Cage circumference	100 m
Cage diameter	32 m
Cage net depth (below water surface)	10 m
Number of fish per cage	27,777
Average feed rate per cage	255 kg d^{-1}
Maximum feed rate per cage	902 kg d^{-1}

Table 2.5. Production information for the 2010 year-class at the Cheney Head salmon farm.

Parameter	Value
Total number of fish	100,000
Lease area	26.5 ha
Number of cages	5
Cage circumference	100 m
Cage diameter	32 m
Cage net depth (below water surface)	10 m
Number of fish per cage	20,000

Table 2.6. Depth layers of current velocity data used in DEPOMOD runs at the Cheney Head salmon farm. The average water depth is the average distance from the water surface to the seafloor at the current meter deployment location, based on Canadian Hydrographic Service bathymetry and tide data.

Farm	Average water depth at current meter (m)	Depth layer	Number of hourly records	Location of depth layer
Cheney Head (MF-503)	15.4	Near surface	983	2.5 m below surface
		Mid-depth	983	7.5 m above bottom
		Near bottom	983	4.5 m above bottom

Table 2.7. DEPOMOD input parameter values.

Parameter	Value
Grid generation module (values set by user)	
Grid cell dimensions (major and minor grids)	10 × 10 m
Number of major grid cells	99 × 99
Number of minor grid cells	98 × 98
Particle tracking module	
Material type	Carbon
Feed release type	Continuous release of feed
Particle information (see Stucchi and Chamberlain 2005)	
Feed water content	10%[1]
Feed digestibility	90%
Feed wasted as % of feed fed	3%[2]
Carbon as % of feed pellets (dry weight)	57%
C as % of feces (dry weight)	33%
Settling velocity of feed pellets (mean)	11.0 cm s^{-1}
Settling velocity of feces (mean ± SD)	3.2 ± 1.1 cm s^{-1}
Current velocity data (see Cromey et al. 2002)	
Current velocity layers	3: near surface, mid-depth, near bottom
Current velocity time step (default value)	3 600 s (1 h)
Turbulence model (default values)	
Random walk model	Yes
Dispersion coefficient (x)	0.100 m^{-2} s^{-1}
Dispersion coefficient (y)	0.100 m^{-2} s^{-1}
Dispersion coefficient (z)	0.001 m^{-2} s^{-1}
Particle trajectory model (default values)	
Number of particles released (for each particle type, per cage, at every time step)	10
Trajectory evaluation accuracy (model time step)	High (60 s)
Resuspension module	
Number of loops to run model for (Cromey et al. 2000)	2
Consolidation time of particles (default value)	4 d
Critical erosion threshold (non-adjustable)	9.5 cm s^{-1}

[1] Feed water/moisture content is typically lower than 10% (Peterson et al. 2005)
[2] Feed wasted as % of feed fed may often be higher than 3% (Stucchi et al. 2005; DFO 2005)

Table 2.8. Summary of current speed data from current meter deployments at the Cheney Head salmon farm. The values shown are based on hourly current speed records (see Table 2.1). A near bottom current speed approximately 9.5 cm s^{-1} corresponds to the critical shear stress threshold for resuspension in DEPOMOD.

	Current speed (cm s^{-1})			% of near bottom records
Depth layer	Minimum	Mean	Maximum	>9.5 cm s^{-1}
Near surface	1.7	15.2	42.7	
Mid-depth	2.2	15.5	39.4	
Near bottom	2.2	14.9	39.7	69

Table 2.9. DEPOMOD mass balance calculations for wastes released from the Cheney Head site with a proposed stocking level of 500,000 fish in 15 cages, and the amount of wastes deposited on seafloor within the model domain (1 × 1 km), using proposed maximum and average feed rates, with resuspension off and on.

	Waste produced per kg feed (kg)	Total waste produced (kg C d^{-1})	% of waste falling within DEPOMOD domain	
Total feed rate (kg d^{-1})			Resuspension off	Resuspension on
16,232 (maximum)	0.044	714	100	0
4,589 (average)	0.044	202	100	0

*Table 2.10. DEPOMOD predictions of contour areas for ranges of carbon deposition rates at the Cheney Head salmon farm with a proposed stocking level of 500,000 fish in 15 cages, using the proposed **maximum** feed rate (902 kg d^{-1} per cage), with resuspension off and on. Oxic A areas exclude areas with background deposition rates (<0.3 g C m^{-2} d^{-1}).*

		Contour area (m^2) (maximum feed rate)		Change due to resuspension	
Site classification	Carbon deposition rate (g C m^{-2} d^{-1})	Resuspension off	Resuspension on	Area (m^2)	% change
Oxic A	0.3-1.0	27,800	0	-27,800	-100
Oxic B	1.0-2.0	13,500	0	-13,500	-100
Hypoxic A	2.0-5.0	18,200	0	-18,200	-100
Hypoxic B	5.0-7.5	8,400	0	-8,400	-100
Hypoxic C	7.5-10.0	6,600	0	-6,600	-100
Anoxic	>10.0	33,800	0	-33,800	-100
>5 g C m^{-2} d^{-1}	>5.0	48,800	0	-48,800	-100

*Table 2.11. DEPOMOD predictions of contour areas for ranges of carbon deposition rates at the Cheney Head salmon farm with a proposed stocking level of 500,000 fish in 15 cages, using the proposed **average** feed rate (255 kg d^{-1} per cage), with resuspension off and on. Oxic A areas exclude areas with background deposition rates (<0.3 g C m^{-2} d^{-1}).*

Site classification	Carbon deposition rate (g C m^{-2} d^{-1})	Contour area (m^2) (average feed rate)		Change due to resuspension	
		Resuspension off	Resuspension on	Area (m^2)	% change
Oxic A	0.3-1.0	22,400	0	-22,400	-100
Oxic B	1.0-2.0	14,200	0	-14,200	-100
Hypoxic A	2.0-5.0	34,200	0	-34,200	-100
Hypoxic B	5.0-7.5	7,400	0	-7,400	-100
Hypoxic C	7.5-10.0	0	0	0	0
Anoxic	>10.0	0	0	0	0
>5 g C m^{-2} d^{-1}	>5.0	7,400	0	-7,400	-100

Table 2.12. Linear relationship between the feed rate (kg d^{-1} per cage) and the highest predicted carbon deposition rate (g C m^{-2} d^{-1}) within the Cheney Head DEPOMOD domain, with a stocking level of 500,000 fish in 15 cages, with resuspension off. The relationship was derived from the predicted highest deposition rates at 3 feed rates: maximum, average, and mid-way through the growout cycle. No relationship was found with resuspension on: all feed rates predicted no deposition within the model domain.

Site	Resuspension	Slope (*b*)	y-axis intercept (*a*)	r^2
Cheney Head (MF-503)	Off	0.024	-0.012	1.0

Table 2.13. Maximum feed and stocking rates to maintain the predicted carbon deposition rate ≤5 g C m^{-2} d^{-1} in all grid cells within the Cheney Head DEPOMOD domain, with a stocking level of 500,000 fish in 15 cages, with resuspension off.

Site	Resus-pension	Proposed stocking rate (number of fish per cage)	Highest predicted deposition rate using proposed maximum feed rate (g C m^{-2} d^{-1})	Feed rate (kg d^{-1} per cage) to maintain deposition rate ≤5 g C m^{-2} d^{-1} in all grid cells	Number of fish per cage to maintain deposition rate ≤5 g C m^{-2} d^{-1} at time of maximum feeding
Cheney Head	Off	27,777	22.0	205	6,300

Table 2.14. Comparisons of Tier 1 sediment sulfide concentrations and DEPOMOD predicted carbon deposition rates at the Cheney Head salmon farm with a total stocking level of 100,000 fish in 5 cages, using actual feed rates at the times of Tier 1 monitoring in 2010 and 2011 (see Table 2.13), with resuspension off. With resuspension on, DEPOMOD predicted no carbon deposition within the model domain in both years. Sulfide values at T1 and T2 are averages of 3 subsamples at each location; maximum sulfide values are the maxima of the 6 subsamples in each year; in both years the maxima were at T2. In both years, the maximum DEPOMOD predicted carbon deposition rate was located within 15 m of the T2 monitoring location.

		Sediment sulfide (Tier 1)		DEPOMOD prediction (resuspension off)	
Year	Sample location	Concentration (µM)	Classification	Deposition rate (g C m^{-2} d^{-1})	Classification
2010	T1	222	Oxic A	1.3	Oxic B
	T2	476	Oxic A	2.9	Hypoxic A
	Maximum	713	Oxic A	3.4	Hypoxic A
2011	T1	219	Oxic A	13.1	Anoxic
	T2	1,191	Oxic B	19.1	Anoxic
	Maximum	1,580	Hypoxic A	22.1	Anoxic

Table 2.15. DEPOMOD predictions of contour areas for ranges of carbon deposition rates at the Cheney Head salmon farm with a total stocking level of 100,000 fish in 5 cages, using actual feed rates at the times of Tier 1 monitoring in 2010 and 2011 (see Table 2.13), with resuspension off and on. Oxic A areas exclude areas with background deposition rates (<0.3 g C m^{-2} d^{-1}).

		Contour area (m^2) 29 Aug-25 Sep 2010 feed rate		Contour area (m^2) 28 Aug-24 Sep 2011 feed rate	
Site classification	Carbon deposition rate (g C m^{-2} d^{-1})	Resuspension off	Resuspension on	Resuspension off	Resuspension on
Oxic A	0.3-1.0	12,200	0	15,900	0
Oxic B	1.0-2.0	6,600	0	7,700	0
Hypoxic A	2.0-5.0	5,800	0	9,300	0
Hypoxic B	5.0-7.5	0	0	3,600	0
Hypoxic C	7.5-10.0	0	0	2,500	0
Anoxic	>10.0	0	0	8,800	0
>5 g C m^{-2} d^{-1}	>5.0	0	0	14,900	0

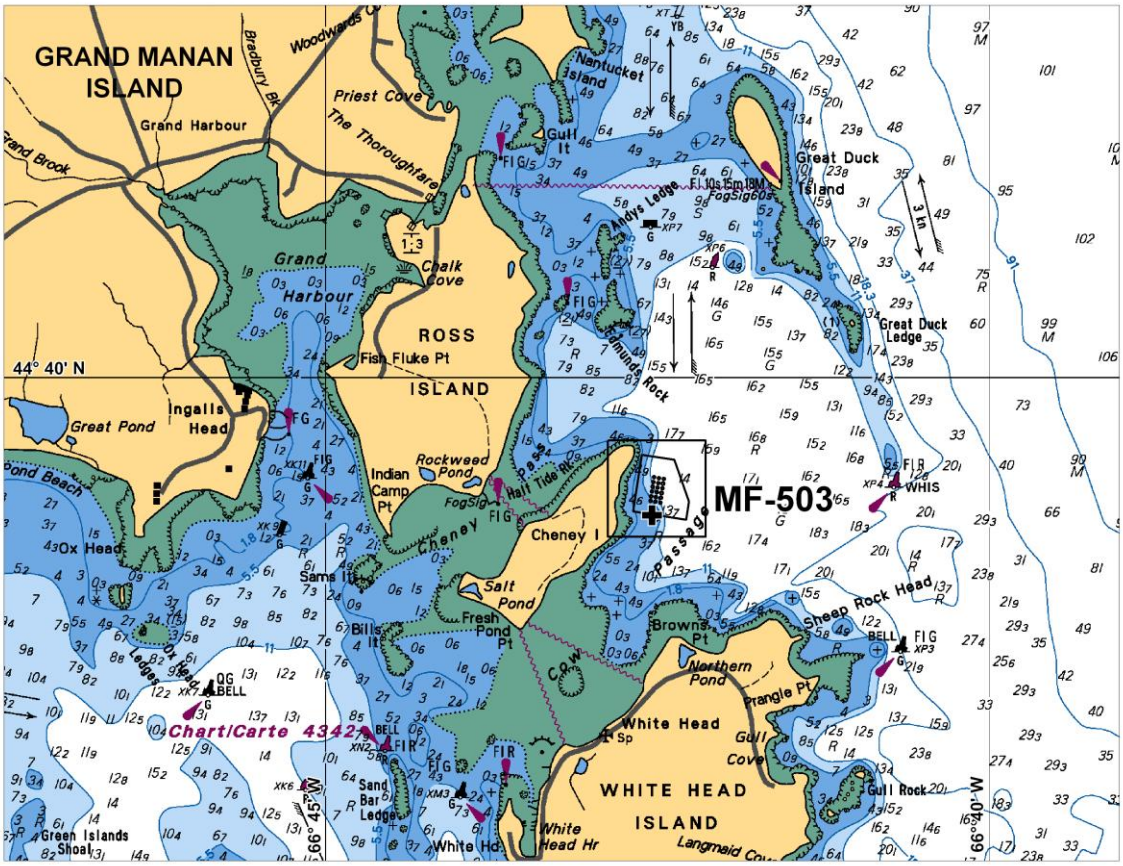

Figure 2.1. Map of the southeastern Grand Manan Island area showing location of the Cheney Head salmon farm (MF-503). The square represents the extent of the DEPOMOD domain. The polygon within the square is the lease boundary. The cross indicates the location of the current meter deployment (CM308). The background map is Canadian Hydrographic Service chart 4340: Grand Manan (2003).

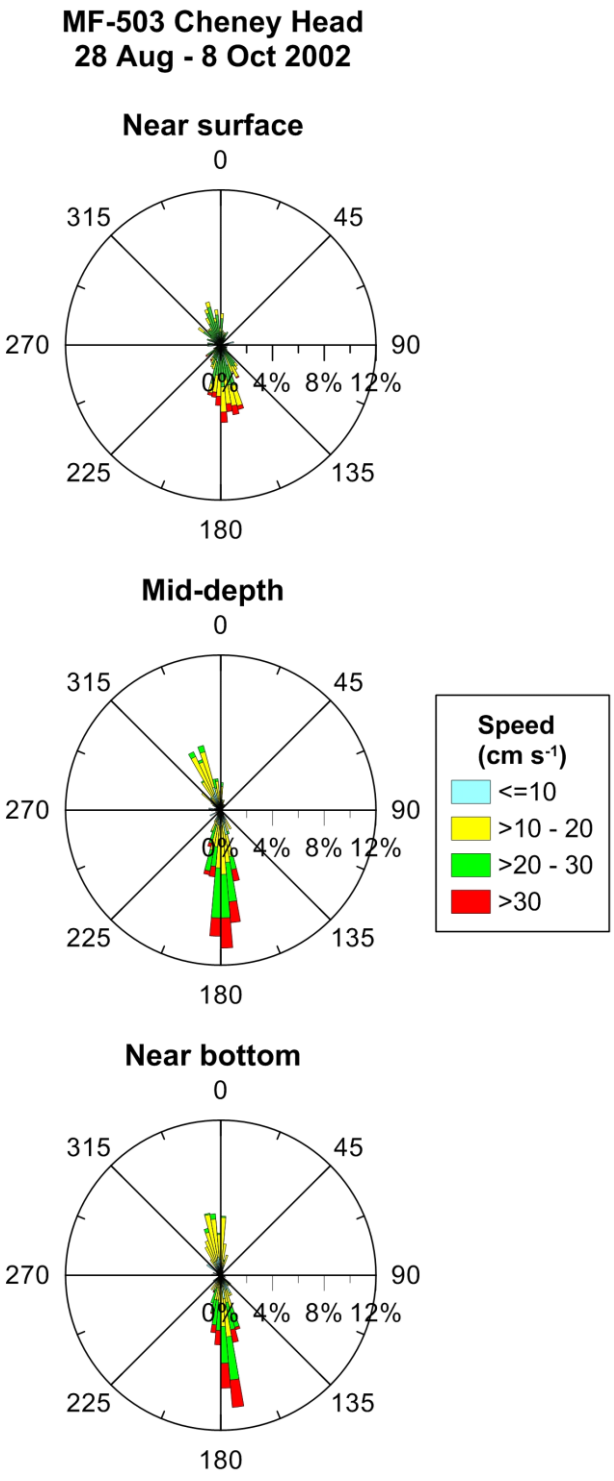

Figure 2.2. Current rose diagrams for ADCP current meter deployment CM308 at the Cheney Head salmon farm (MF-503). Data shown are based on hourly records at three depth layers: near-surface (top), mid-depth (middle), and near-bottom (bottom).

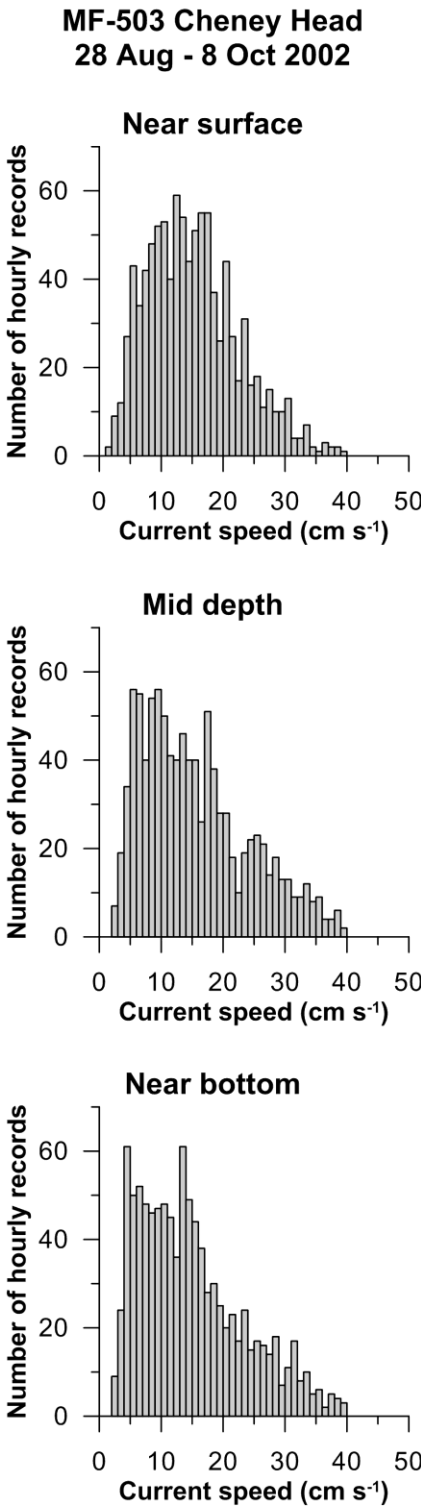

Figure 2.3. Current speed histograms for ADCP current meter deployment CM308 at the Cheney Head salmon farm (MF-503). Data are shown based on hourly records at three depth layers: near-surface (top), mid-depth (middle), and near-bottom (bottom).

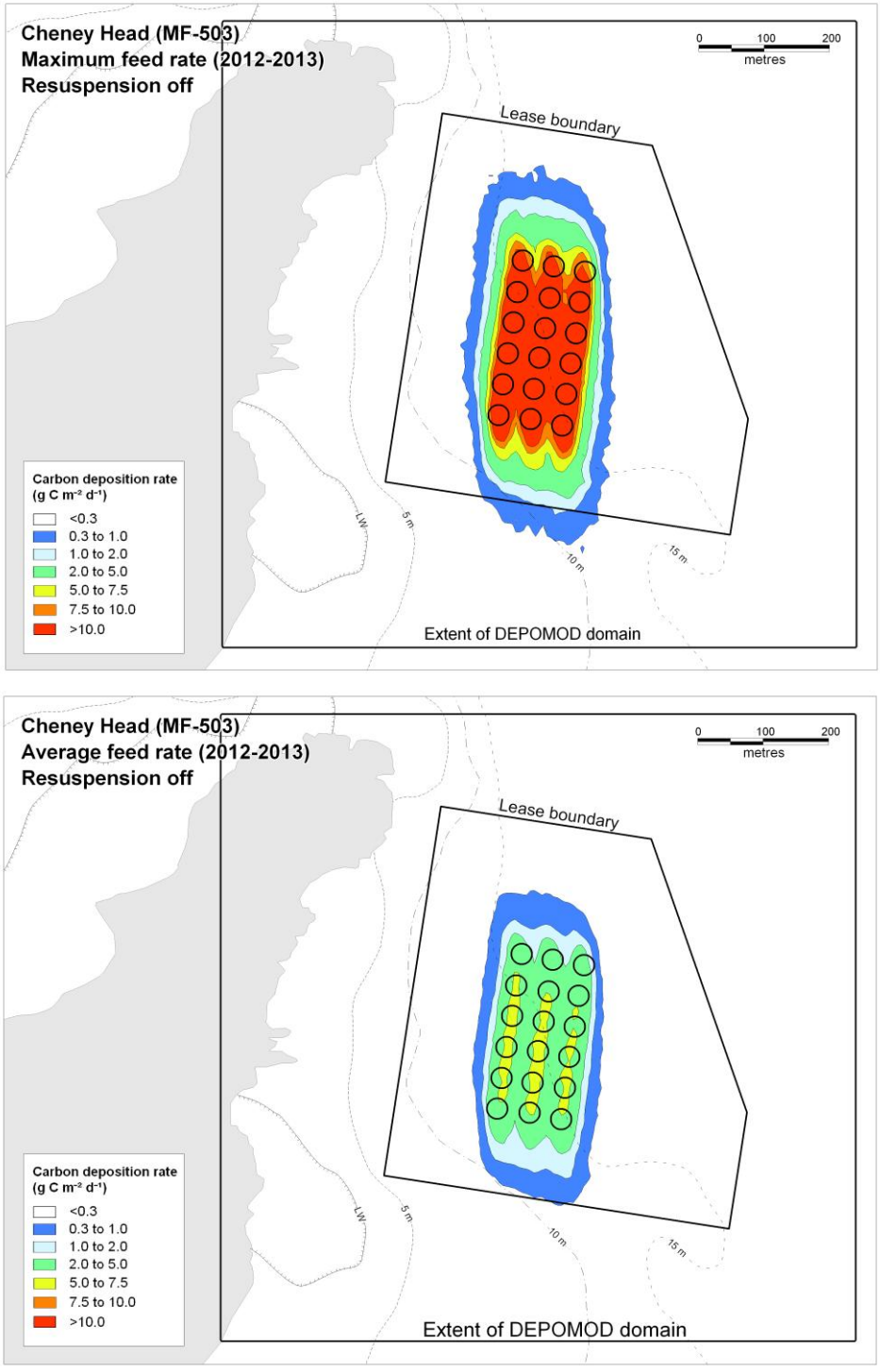

*Figure 2.4. Contour plot of DEPOMOD predicted carbon deposition rates at the Cheney Head salmon farm (MF-503), with a total of 500,000 fish in 18 cages, using the proposed **maximum** feed rate (902 kg d^{-1} per cage; top) and the proposed **average** feed rate (255 kg d^{-1} per cage; bottom), with resuspension off. With resuspension on, there was no waste deposition predicted within the model domain at both feed rates.*

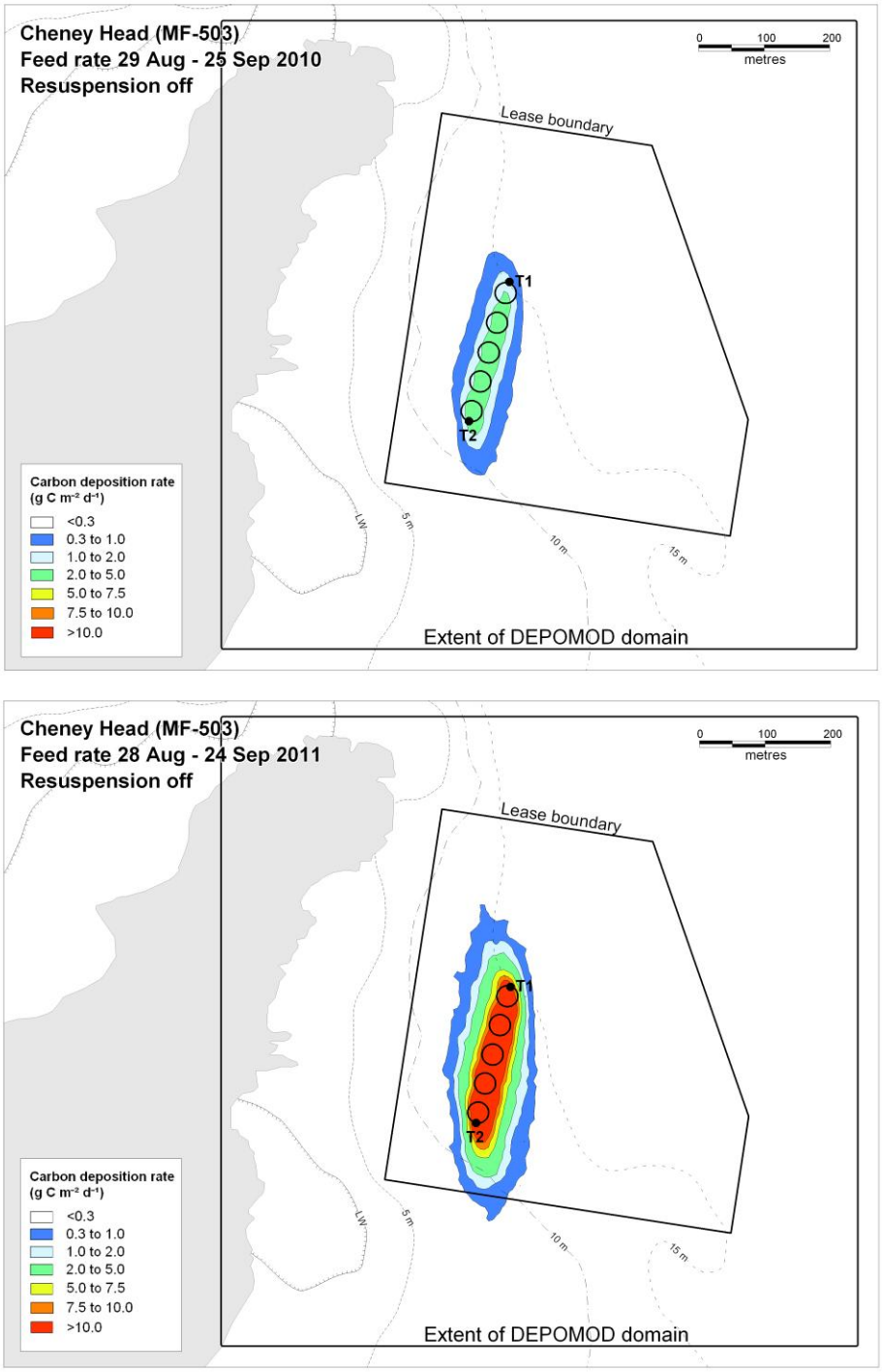

Figure 2.5. Contour plots of DEPOMOD predicted carbon deposition rates, with resuspension off, at the Cheney Head salmon farm (MF-503), with a total of 100,000 fish in 5 cages, using actual feed rates at the times of Tier 1 monitoring in September 2010 (average 160 kg d^{-1} per cage; top) and September 2011 (average 1,069 kg d^{-1} per cage; bottom). With resuspension on, there was no waste deposition within the model domain (both years). Black dots indicate locations of Tier 1 samples (T1 and T2). Circles indicate approximate cage locations.

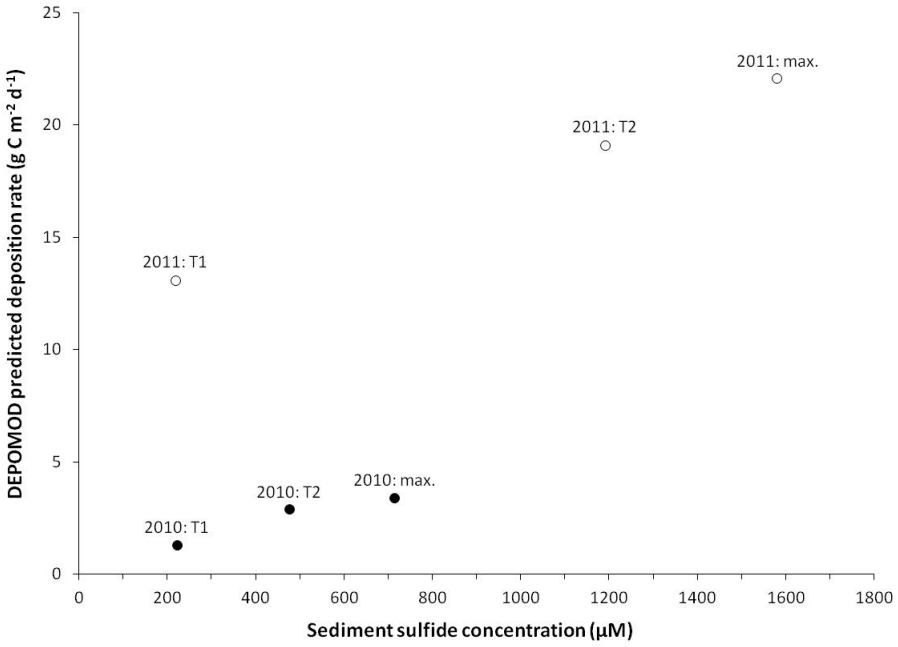

Figure 2.6. Relationships between sediment sulfide concentrations in Tier 1 monitoring vs. DEPOMOD predicted carbon deposition rates (resuspension off) at the Cheney Head salmon farm (MF-503), with approximately 100,000 fish in 5 cages. Tier 1 monitoring was conducted in September 2010 (●) and September 2011 (○). Sulfide values shown are averages of 3 subsamples at monitoring locations T1 and T2, and the maxima of all 6 subsamples in each year. DEPOMOD values are predicted deposition rates at locations T1 and T2, and the maxima of all values within the DEPOMOD domain, using feed rates at the times of Tier 1 monitoring; in both years, the maximum predicted deposition rates were located near T2.

References

Cromey, C.J., T.D. Nickell, and K.D. Black. 2000. DEPOMOD (v2.2.1) user manual. Scottish Environment Protection Agency, Stirling, UK.

Cromey, C.J., T.D. Nickell, and K.D. Black. 2002. DEPOMOD – modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214: 211-239.

DFO. 2005. Assessment of Finfish Cage Aquaculture in the Marine Environment. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2005/034.

Hargrave, B.T. 1994. A benthic enrichment index. *In:* B.T. Hargrave (ed.) Modelling benthic impacts of organic enrichment from marine aquaculture. Can. Tech. Rep. Fish. Aquat. Sci. 1949: 79-91.

NBDENV (New Brunswick Department of Environment). 2006. The Environmental Management Program for the Marine finfish Cage Aquaculture Industry in New Brunswick, version 2.0. NBDENV, Fredericton, NB. 21 p. Available at: http://www.gnb.ca/0009/0369/0017/pdfs/0010-e.pdf (accessed July 2012).

Petersen, S.A., T.F. Sutherland, and D. Higgs. 2005. Physical and chemical characterization of salmonid feed pellets. Can. Data. Rep. Fish. Aquat. Sci. 1159: iv + 12 p.

Stucchi, D.J., and J. Chamberlain. 2005. DEPOMOD Canada Methods and Settings V2.0. Fisheries and Oceans Canada, Pacific Region. (unpublished document).

Stucchi, D., T. Sutherland, C. Levings, and D. Higgs. 2005. Near-field depositional model for salmon aquaculture waste. Hdb. Env. Chem. 5(M): 1-23.

This Report is Available from the:

Centre for Science Advice (CSA)
Maritimes Region
Fisheries and Oceans Canada
PO Box 1006, Station B203
Dartmouth, Nova Scotia
Canada, B2Y 4A2

Telephone: 902-426-7070
Fax: 902-426-5435
E-Mail: XMARMRAP@mar.dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas

ISSN 1919-3750 (Print)
ISSN 1919-3769 (Online)

La version française est disponible à l'adresse ci-dessus.

Correct Citation for this Publication:

DFO. 2013. DEPOMOD Predictions for an Aquaculture Site at Cheney Head, New Brunswick. DFO Can. Sci. Advis. Sec. Sci. Resp. 2012/035.